

CO₂ emissions, energy consumption, economic and population growth in Malaysia



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ABSTRACT

This study investigates the dynamic impacts of GDP growth, energy consumption and population growth on CO₂ emissions using econometric approaches for Malaysia. Empirical results from ARDL bounds testing approach show that over the period of 1970–1980, per capita CO₂ emissions decreased with increasing per capita GDP (economic growth); however from 1980 to 2009, per capita CO₂ emissions increased sharply with a further increase of per capita GDP. This is also supported by the dynamic ordinary least squared (DOLS) and the Sasabuchi–Lind–Mehlum *U* (SLM *U* test) tests. Consequently, the hypothesis of the EKC is not valid in Malaysia during the study period. The results also demonstrate that both per capita energy consumption and per capita GDP has a long term positive impacts with per capita carbon emissions, but population growth rate has no significant impacts on per capita CO₂ emission. However, the study suggests that in the long run, economic growth may have an adverse effect on the CO₂ emissions in Malaysia. Thus, significant transformation of low carbon technologies such as renewable energy and energy efficiency could contribute to reduce the emissions and sustain the long run economic growth.

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1. Introduction

The global concern for environmental sustainability is apparent in an increasing public mandate, and the development strategy largely depends on whether the enduring economic growth causes

environmental degradation or whether such growth is sufficient to compensate for the environmental cost of production or development process. Nevertheless, exhaustible natural resources serve as inputs into the production or development process. If the functional relationship between natural resources and modern development processes cannot be avoided, then harm to the environment is inevitable [1]. The prevalence of such problems is higher in countries such as Malaysia, where economic growth, energy security and environmental sustainability are simultaneously important.

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In Malaysia, the government has set a voluntary target to reduce 40% carbon emission intensity [2] as well as a goal of achieving high income nation by 2020 [3]. Thus, a significant concern is whether the goals of higher economic growth and improved environmental quality (emission reduction) are mutually exclusive. For instance, Jorgenson and Wilcoxen [4] observed that slow economic growth coincided with the advent of environmental regulations when petroleum prices increased in the United States of America (USA). However, the Malaysian economy subsidises petroleum prices [5] which alternatively encourages additional energy consumption. Such subsidised prices might be conducive for accelerating economic growth. Moreover, from 1970 to 1980, Malaysia's economic dominance shifted from the primary sector (mainly agricultural) to the secondary sector (industrial) [6]; consequently, the energy consumption rose substantially. Currently, the economic development in Malaysia is moving towards the services sector, which is a highly energy intensified sector. Therefore, achieving a reduction of 40% emission intensity might be distorted, unless the economy substantially shifts to the use of low carbon technology (renewable energy and energy efficient) to produce the goods and services. Although the theory of the environmental Kuznets curve (EKC) refers to an early stage of economic development, whereby a small portion of the excess income achieved by industrialisation is positively associated with environmental problems [1]. Therefore, this study aims to investigate the dynamic impacts of GDP growth, energy consumption and population growth on the CO₂ emissions in Malaysia by applying the ARDL bounds testing approach and dynamic OLS. Moreover, the Sasabuchi–Lind–Mehlum (SLM) *U* Test and the Quadratic and Polynomial Confidence Interval diagram are also performed to check the robustness.

2. Review of literature

A number of empirical studies investigated the relationship between CO₂ emissions and economic growth for a group of developed and or developing countries such as, BRIC countries [7]; MENA countries [8]; OECD countries [9]; industrialised countries [10]; and small-economy countries [11]. Most of these studies especially on the EKC provide a simple path of economic growth and environmental problems such as emissions or pollutions. Some studies also focused this relationship on a single country for instance, Bangladesh [12]; China [13–19]; Turkey [20]; South Korea [21,22]; India [23]; Nigeria [24]; and the USA [25,26]. The relationship between CO₂ emission and economic growth may appear a linear, U shape, inverted U shape or any other shapes [27].

However, some studies confirmed the EKC hypothesis with an inverted U-shaped relationship [28–34,21] which indicates an

additional increase of economic growth improves the environmental quality i.e. emission reduction. In contrast, many studies found non-existence of EKC, indicates increasing economic growth leads a greater environmental degradation (e.g. [35–40]). However, Holtz-Eakin and Selden [41] found a monotonic rising curve, whereas others found a non-monotonic relationship [42–45]. Furthermore, Shafik [44] and Grossman and Krueger [1] found an N-shaped curve while Ozturk and Acaravci [46] found no causal relationship between CO₂ emission and GDP per capita. In addition, a few studies found a unidirectional causality from energy consumption to aggregate output or income [47–49] whereas other studies found bi-directional causality between energy consumption and aggregate output [50–55]. Nevertheless, each of these studies has its own merits for better understanding of the paradox of economic growth and environmental balance.

In Malaysia, there is a very limited study on the dynamic impacts between economic growth, CO₂ emissions and other variables. Table 1 summarises their findings, analytical techniques and limitations. A few studies found a positive and bidirectional relationship whereas Saboori et al. [56] found an existence of EKC for Malaysia from 1980 to 2009. Unlike these relationships, a few studies also demonstrated the evidences of CO₂ emission reduction with policies such as public transport and waste to green energy [57–59].

Based on the above literatures, the empirical results demonstrated a varied relationship. This might be due to the selection of different samples (a country/few country/a region); time periods; variables and analytical techniques. However, this study would be the first attempt to investigate the dynamic relationships between CO₂ emissions and other variables such as, energy consumption, GDP per capita and population growth in Malaysia. The energy consumption and population growth includes as explanatory variables because omitted variables may often produce misleading results from the OLS estimator [60] which also helps to fill the research gaps.

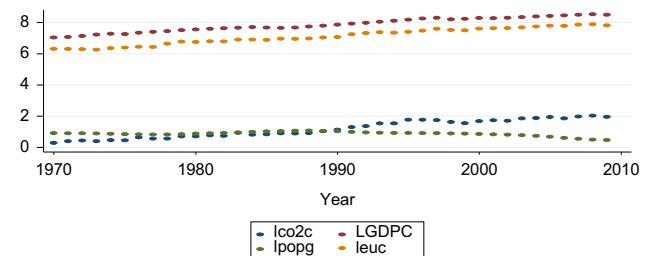


Fig. 1. Logarithmic trend of per capita CO₂ emissions, GDP and energy consumption; and population growth rate.

Table 1

Summary of studies on economic growth, CO₂ emissions and other variables in Malaysia.

Relationships and sources	Techniques	Limitations ^a
Positive relationship between economic growth and energy consumption, and emissions; Ang [61]	Johansen cointegration; VECM-based Granger causality test	Did not consider the quadratic form of GDP per capita to examine the existence of EKC.
Predicted CO ₂ emissions and energy consumption should be tripled to maintain the GDP at 4.6% by 2030; Gan and Li [62]	Ordinary least squares (OLS) estimation	No unit-root test, although macroeconomic variables are likely to be characterised by unit root processes [64].
Bidirectional relationship between CO ₂ emissions and economic growth; Azlina and Mustapha [63]	Johansen cointegration test; VECM-based Granger causality test	Presence of mixed-order integration. Johansen technique is highly sensitive to the selection of optimal number of lags [65].
CO ₂ emissions decrease with an increase of GDP per capita, which indicates the existence of EKC; GDP per capita and its quadratic form as explanatory variables; Saboori et al. [56]	ARDL bounds testing to Cointegration; VECM-based Granger causality test	Ignore other variables, such as energy consumption and population. Inclusion of the quadratic form of the GDP per capita fulfils the necessary conditions for the existence of an inverted U-shaped relationship but not sufficient conditions [66].

^a Author's view.

3. Outlook of Malaysia's economy, energy consumption and emissions to 2030

Gan and Li [62] estimated the expected GDP growth of Malaysia averaged 4.6% between 2004 and 2030, and the actual GDP would reach US\$341.6 billion by 2030 compared to US\$107 billion in 2004. A structural change may occur in Malaysia for instance, the output of agriculture sector might drop by 3%, whereas the industrial and service sectors might marginally increase over the period of 2004–2030. In addition, it is anticipated that the per capita real GDP would reach US\$8690 in 2030 from US\$ 4296 in 2004. However, Gan and Li [62] also projected that energy consumption would also increase by 4.3% in 2030 to keep pace with economic growth. Although the growth rate of energy consumption is a bit lower than the GDP growth rate, the absolute amount of energy consumption would be 3 times greater.

Fig. 1 illustrates the logarithmic form of CO₂ emissions per capita, GDP per capita, energy consumption per capita, and population growth rate. It clearly demonstrates that the CO₂ emissions per capita, GDP per capita, and energy consumption per capita are constantly increasing, whereas the population growth rate is decreasing. The rising intensity of CO₂ emissions is of a great concern due to the Malaysia's rapid economic growth.

In Malaysia, power sector (electricity) is the major source of energy consumption and CO₂ emissions. This sector accounted for approximately 36% of the total global CO₂ emissions from oil in 2004 [67]. Among all the greenhouse gases, CO₂ emissions are responsible for more than 60% of the greenhouse gas effects, which cause to global warming and climate change. Therefore, mitigation or reduction of CO₂ emissions became a global concern to secure sustainable energy as well as to minimise the adverse effects of climate change.

4. Data and analysis

The study used annual time series data from 1970 to 2009 for Malaysia, which were obtained from the world development indicator (WDI) dataset. The variables of interest included CO₂ (carbon dioxide) emissions per capita (metric tons per capita) as a dependent variable and GDP per capita (GDPC), energy consumption/use (kg of oil equivalent per capita) (EUC) and population growth (POPG) as explanatory variables. The rational for specifying the employed model and variables chosen discussed as follows.

The empirical model of this study derives by the following standard Cobb–Doglus production function with constant returns, the aggregate output function can be displayed at time t as follows:

$$Y_t = F(K_t, AL_t)$$

where Y_t is GDP, K_t is capital and AL_t is the effective labour.

Since it is widely assumed that CO₂ emission is discharged by economic activities, therefore CO₂ emission function can be written as:

$$CO_2(t) = \nu(F(Y(t))$$

where, ν represents a certain rate of CO₂ emission from the production function.

In the production function, all forms of capital are not responsible for CO₂ emission while burning of energy, e.g. oil, coal, gas and electricity are mainly responsible for discharging CO₂ emission. Hence, total capital can be the composition of emitting capital (K_e) and non-emitting capital (K_n) as shown below

$$K = K_e + K_n$$

Therefore, CO₂ emission function can be rewritten as:

$$CO_2(t) = \phi K_e(Y)$$

Since, Y is the function of labour and capital; hence, population growth can be taken as a proxy.

Moreover, the concentration of emissions is increasing as a consequence of various human activities where population growth has been a core factor to explain CO₂ emission dynamics [68]. Thus, the model can be written as:

$$\ln CO_{t2} = \beta_0 + \beta_1 GDP_t + \beta_2 K_{Pt} + \beta_3 PG_t + \varepsilon_t$$

Since, Grossman and Krueger (1995) have shown a non-linear relation between GDP and CO₂ emission that can be reflected by the following equation:

$$\ln CO_{t2} = \beta_0 + \beta_1 \ln GDP_t + \beta_2 \ln GDP_t^2 + \beta_3 \ln K_{Pt} + \beta_4 PG_t + \varepsilon_t \quad (1)$$

Hence, this study employed the autoregressive distributed lag (ARDL) technique developed by Pesaran et al. [69] to assess the long-run relationship and the changes of the key variables. The key characteristics of this technique include (i) a cointegration relationship estimated using OLS and estimation performed after selecting the respective lag order appropriate for the model; (ii) an applied technique that remains statistically significant, regardless of the nature of the variable integration (i.e., either $I(0)$ or $I(1)$ or mutual co-integrated) that typically explains the position that the unit root tests may not be necessary, notwithstanding the Johansen and Jeslius approaches; and (iii) a requirement that the test is valid for a small and finite data size. Based on Eq. (1), the ARDL version of the vector error correction model (VECM) can be specified as Eq. (2).

$$\begin{aligned} \Delta \ln CO_2 = & \beta_0 + \beta_1 \ln CO_{2t-1} + \beta_2 LGDPC_{t-1} + \beta_3 GDPS_{t-1} + \beta_4 POPG_{t-1} \\ & + \sum_{i=1}^p \gamma_i \ln CO_{2t-i} + \sum_{j=1}^q \delta_j \Delta GDPG_{t-j} \\ & + \sum_{l=1}^q \varphi_l \Delta GDPS_{t-l} + \sum_{m=1}^q \eta_m POPG_{t-m} + \sum_{r=1}^q \xi_r EUC_{t-r} + \varepsilon_t \end{aligned} \quad (2)$$

The estimation procedure begins with Eq. (2) and uses OLS to enable the Wald test or F -test to determine the joint significance of coefficient of the lagged variables. The essence of this procedure is to examine the likelihood of any possible long-run relationship among the respective variables. In this regard, the null hypothesis (H_0) $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$ explains that cointegrating relationships do not exist among the regressors and the regressand: therefore, the alternate hypothesis is (H_a) $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq 0$. The F -statistics can be compared against the critical values of the upper and lower bounds, as in Pesaran et al. [69]. Thus, the whole notion of this arrangement is that if the F -statistics are higher than the upper critical value, then the null hypothesis shows that a cointegrating relationship does not exist. So, the null hypothesis is rejected. This means that the long-run relationship exists among the respective variables, whereas if the F -statistics are less than the lower critical value, the null hypothesis is accepted. Alternatively, if the F -statistics are observed to be within the lower and upper critical values, then the test is inconclusive. When this procedure is completed, the next step is to proceed with the estimation of the long-run coefficient of the ARDL model using Eq. (3).

$$\begin{aligned} \ln CO_2 = & \beta_0 + \sum_{i=1}^p \gamma_i \ln CO_{2t-i} + \sum_{j=0}^{q1} \delta_j GDPG_{t-j} + \sum_{l=0}^{q2} \varphi_l GDPS_{2t-l} \\ & + \sum_{m=0}^{q3} \eta_m POPG_{t-m} + \sum_{r=0}^{q4} \psi_r \ln EUC_{t-r} + \varepsilon_t \end{aligned} \quad (3)$$

This study also estimates the error correction model presented in Eq. (4) to investigate the short-run dynamics of the respective

variables along with the short-run adjustment rate towards the long-run rate.

$$\Delta \ln \text{CO}_2 = \beta_0 + \sum_{i=1}^p \gamma_i \Delta \ln \text{CO}_{2t-i} + \sum_{j=1}^q \delta_j \Delta \text{GDPG}_{t-j} + \sum_{l=1}^q \varphi_l \Delta \text{GDPGS}_{2t-l} + \sum_{m=1}^q \eta_m \Delta \text{POPG}_{t-m} + \sum_{r=1}^q \psi_r \Delta \ln \text{EUC}_{t-r} + \theta \text{emc}_{t-1} + \varepsilon_t \quad (4)$$

Finally, this study examines the stability tests of the coefficients by employing the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ) according to the method by Pesaran and Pesaran [70]. In addition, this study also conducts the Sasabuchi–Lind–Mehlum (SLM) *U* test to ensure the inverted U-shaped relationship. It should be noted that Lind and Mehlum [66] created and altered the likelihood ratio test of Sasabuchi, which is referred to as the Sasabuchi–Lind–Mehlum (SLM) *U* test.

5. Results and discussion

As mentioned in the methodology section, prior to the estimation of cointegration, it is not necessary to check the order of integration of the respective variables for the methodology of Pesaran et al. [69]. However, this study conducted the unit root for two reasons: first to ensure that no variable surpassed the order of integration $I(1)$ and then to justify the appropriateness of applying the ARDL approach rather than the standard cointegration approaches. Therefore, the Dickey–Fuller generalised least squared (DFGLS) approach is employed based on the trends and constants to examine the autoregressive unit root by Elliot et al. [71]. The DFGLS is a simple modified version of the conventional augmented Dickey–Fuller (ADF) *t*-test that de-trends the series prior to the estimation of ADF test regression.

Table 2 shows that the logarithmic form of CO_2 emissions (per capita) was stationary at $I(0)$. However, the LGDPC was found to non-stationary at $I(0)$, but it was stationary after taking first difference. The DFGLS test also revealed that the population growth rate was non-stationary at $I(0)$ but stationary at $I(1)$. Similarly, the energy use (per capita) was stationary at $I(1)$ rather than at $I(0)$. Therefore, the presence of such mixed orders of integration, as reported in the DFGLS test, endorsed the application of the ARDL approach instead of conventional econometric approaches. Before estimating Eq. (2), the optimum lag has been identified. Based on the results reported in Table 3, the study selects the optimum lag to be 3, according to the Schwarz information criterion.

To examine the cointegrating relationship, Wald test or *F*-test for the joint significance of the coefficient of the lagged variables was applied. Therefore, the null hypothesis (H_0) $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$ explained the existence of no cointegration against the alternative hypothesis of $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq 0$, which showed that cointegration existed. Table 4 reports the results of the

Table 2

Results from Dickey–Fuller generalised least squared (DFGLS) unit root test with trends and constants.

Log levels (Z_t)			Log 1st difference (Z_t)			$I(d)$
Variable	SIC lag	DFGLS stat	Variable	SIC lag	DFGLS stat	
LCO_2	1	-2.306 ^{**}	ΔLCO_2	0	-8.737 ^{***}	$I(0)$
LGDPC	0	-1.684 ^{***}	ΔLGDPC	1	-4.873 ^{***}	$I(0)$
POPG	3	-2.061	ΔPOPG	2	-4.114 ^{**}	$I(1)$
EUC	0	-2.331	ΔEUC	0	-6.083 ^{***}	$I(1)$

Note: Statistically significant at 1% (**), 5% (**) and 10% (*) level.

Table 3
Lag length selection criteria for cointegration.

Lag	Log <i>L</i>	LR	FPE	AIC	SC	HQ
0	-340.310	NA	4119.191	19.674	19.852	19.736
1	-194.502	249.954	2.493	12.257	13.146	12.564
2	-149.216	67.279	0.486	10.583	12.183	11.136
3	-108.263	51.486 ^a	0.129	9.157	11.468 ^a	9.955
4	-92.448	16.266	0.161	9.168	12.190	10.211
5	-64.463	22.387	0.119 ^a	8.483 ^a	12.216	9.772 ^a

LR: sequential modified LR test statistic (each test at the 5% level) FPE: final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan–Quinn information criterion.

^a Indicates lag order selected by the criterion.

calculated *F* statistics in which each variable was normalised as the dependent variable.

The calculated *F* statistic $F_{\text{CO}_2}(\text{CO}_2|\text{LGDPC}, \text{LGDPCS}, \text{POPG}, \text{EU}) = 5.444$ is greater than the upper bound critical value of Pesaran et al. [69] at the 1% significance level (4.15). This result indicates that the null hypothesis of no cointegration was rejected. Along with the Pesaran critical value, this study was also used the Narayan [72] critical value to compare the calculated *F*-statistics obtained from the Wald joint test of significant of the respective lagged variables. The Narayan [72] critical values were developed through the application of stochastic simulations specific to the sample size based on 40,000 replications.

However, the null hypotheses of no cointegration were still rejected because the calculated *F* value of the joint test (5.444) was greater than the upper bound critical value of Narayan [72] (4.223) at the 5% significant level when CO_2 emission is normalised. Thus, the long-run cointegrating relationship among the respective variables was recognised when CO_2 emissions were normalised as regressive. Nevertheless, when the GDP growth and energy consumption per capita were considered dependent variables, the calculated *F*-statistics fell below the lower bound of the critical values of Pesaran [69] and Narayan [72], which implied that no long-run cointegration existed when these two variable were normalised. Conversely, when population growth was considered as a dependent variable, the calculated *F*-statistics fell between the upper and lower bounds of the critical value; therefore, the evidence of this relationship is inconclusive.

After identifying the co-integration relationship, this study preceded to estimate Eq. (3) by following the ARDL specifications (1, 0, 0, 0, 1) to reveal the long-run elasticity of the respective variables on the CO_2 emissions.

The estimated long-run coefficient of LGDPC was negative and statistically insignificant, which implied that the CO_2 emissions initially fell with a rise of GDP per capita as shown in Table 5. However, the coefficient of the quadratic form LGDPC (LGDPCS) was positive and statistically significant, which indicated that the relationship between CO_2 emissions and economic growth was non-monotonic. These relationships are clearly demonstrated in Figs. 2 and 3, in which CO_2 emissions decreased from 1970 to 1978 and then smoothly increased from 1978 to 2012. According to Brock and Taylor [73], the relationship between economic growth and environmental quality largely depends on three important mechanisms such as scale of production, composition or means of production and use of technology for production. In relation to the study findings, during the period of 1970–1978, composition of production factor was less responsive towards CO_2 emission, indicated that an increase of GDP per capita might be helpful to reduce per capita CO_2 emission. However, over the period of 1978–2009, the positive coefficient of LGDPCS shows higher growth rate of CO_2 emission than GDP. This might be happened as agricultural sector contributed more than 25% of Malaysian GDP from 1970 to

Table 4

Results of the bounds tests of Eq. (1).

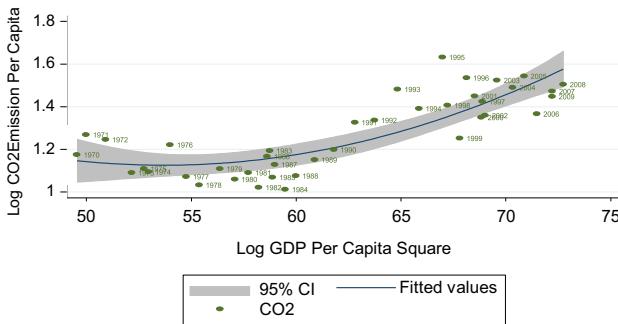
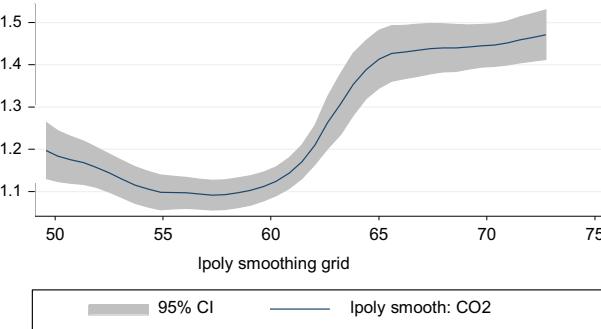
Dep. var.	SIC lag	F-statistic	Probability	Outcome
$F_{CO_2}(CO_2 LGDPC, LGDPCS, POPG, EU)$	3	5.444***	0.002	Cointegration
$F_{LGDPC}(LGDPC CO_2, LGDPCS, POPG, EU)$	3	1.760	0.165	No cointegration
$F_{POPG}(POPG CO_2, LGDPC, LGDPCS, EU)$	3	2.671	0.051	Inconclusive
$F_{EUC}(EUC CO_2, LGDPC, LGDPCS, POPG)$	3	0.648	0.666	No cointegration
Critical value, Pesaran et al. [69]	I(0)	I(1)	Narayan [72] I(0)	I(1)
1% Significance level	3.29	4.37	4.280	5.840
5% Significance level	2.56	3.49	3.058	4.223
10% Significance level	2.20	3.09	2.525	3.560

Note: Statistically significant at 1% (***).

Table 5Estimated long run coefficients using the ARDL approach (1, 0, 0, 0, 1) based on the Schwarz Bayesian criteria. The dependent variable is per capita CO₂ emission, and 38 observations were used for estimations from 1972 to 2009.

Regressor	Coefficient	Standard error	T-ratio [Prob]
LGDPC	-0.021	0.013	-1.630 [0.113]
LGDPCS	0.002**	0.001	2.337 [0.026]
POPG	0.001	0.097	0.012 [0.990]
EUC	0.235***	0.510	4.607 [0.000]
C	0.869***	0.287	3.019 [0.005]

Note: Statistically significant at 1% (***), 5% (**) and 10% (*) level.

**Fig. 2.** Inverted U shaped relations between per capita emissions and GDP.**Fig. 3.** Inverted U shaped and upwards trends.

1978 (WDI, 2014) and then share of agriculture to the GDP was decreased while shares of manufacturing and service sector were risen. Al-Mamun et al. [74] also revealed that economic transformation from industrial to service sector leads to reduce CO₂ emission in middle and lower middle-income countries. Despite in OECD and high-income countries, technologically advanced and energy-led service sector increases CO₂ emission level [74]. Likewise increasing service-led economy emits more CO₂ emission

Table 6Error correction representation of the ARDL model (1, 0, 0, 0, 1) based on SIC. The dependent variable is ΔCO_2 , and 38 observations were used for the estimations from 1972 to 2009.

Regressor	Coefficient	Standard error	T-ratio [Prob]
$\Delta LGDPC$	-0.011	0.006	-1.900 [0.066]
$\Delta LGDPCS$	0.001	0.655	2.386 [0.023]
$\Delta POPG$	0.662	0.053	0.012 [0.990]
ΔEUC	0.630	0.186	3.375 [0.002]
ΔC	0.477	0.207	2.296 [0.028]
ecm (-1)	-0.549	0.147	-3.723 [0.001]

$$ecm = CO_2 + 0.021832 \times LGDPC - 0.0028490 \times LGDPCS - 0.0012056 \times POPG - 0.2354E-3 \times EUC - 0.86958 \times C$$

compared to other sectors [73,75]. Moreover, some studies also demonstrated that higher national income does not necessarily mean a greater amount of pollutant emissions [76–79].

The findings of positive relationship between economic growth and CO₂ emissions are partially in line with other Malaysian studies of Ang [61] and Azlina and Mustapha [63] although they did not follow an EKC path. In contrast, Saboori et al. [56] found an existence of EKC for Malaysia. The differences of this study findings may occur due to the two additional control variables, such as energy consumption and population growth and longer time period of 1970–2009 whereas Saboori et al. [56] considered only the GDP per capita and its quadratic form as explanatory variables for a period of 1980–2009. Furthermore, measuring the nonlinearity by taking the quadratic form fulfilled the necessary condition for the existence of a U or inverted U shaped relationship but did not provide the sufficient conditions, as indicated by Sasabuchi–Lind–Mehlum (SLM) U test.

The model also found a positive but insignificant coefficient of population growth. This indicates that population growth was not the main responsible to impact the CO₂ emissions in Malaysia. However, energy consumption per capita had a strong and positive impact on CO₂ emission, as a huge proportion of CO₂ emissions in Malaysia comes from energy consumption of the power, industrial and transport sectors. This relationship is in line with many other studies e.g. [10,20,61,80,81]. However, technological progress reduces CO₂ emission intensity by increasing energy efficiency [13–17] where carbon free new-technology (e.g. wind, nuclear) is conducive in reducing CO₂ emission without harming the economic growth [82].

Alike the long-run relationship, the short run LGDPC led to an approximate 1.1% decrease, whereas the LGDPCS led to 0.1% increase in CO₂ emissions (Table 6). In addition, Table 6 reports that population growth does not foster emissions in the short run. However, in the short run as expected, the energy consumption per capita had a positive and significant impact on the CO₂ emissions. The coefficient of the equilibrium correction mechanism (ECM) was 0.549, which was significant at the 1% significance

Table 7
ARDL-VECM model diagnostic tests.

$R^2 = 0.83$, Adjusted $R^2 = 0.80$	C: Normality $\chi^2(2) = 1.079[0.583]$
A: Serial Correlation $\chi^2(1) = 0.012[0.912]$	D: Heteroscedasticity $\chi^2(1) = 0.448[0.503]$
B: Functional Form $\chi^2(1) = 1.828[0.176]$	

A: Lagrange multiplier test of residual serial correlation; B: Ramsey's RESET test using the square of the fitted values; C: Based on a test of skewness and kurtosis of residuals; D: Based on the regression of squared residuals of the squared fitted values.

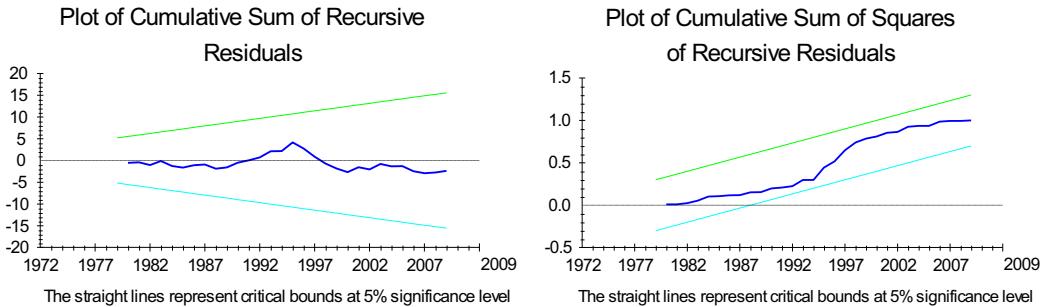


Fig. 4. Plot of CUSUM and CUSUMQ for coefficients stability of ECM model (critical bounds at 5% significance level).

level and implied that disequilibrium in the short run was adjusted by 54% per year towards the long-run equilibrium.

The model diagnostics for the value of R^2 and adjusted R^2 were 83% and 80%, respectively, which indicated that the model was well fitted. The ARDL test also passed several diagnostic tests, with no serial correlations, functional errors, normality, or heteroscedasticity problems of the models estimated in this study (Table 7).

The cumulative sum (CUSUM) and cumulative sum of squares (CUSUMQ) plots (Fig. 4) from a recursive estimation of the model also indicated that the model was stable because the residuals were within the critical bounds of the 5% significance level.

6. Robustness analysis

6.1. Dynamic OLS

The robustness of the long run coefficients obtained from the ARDL estimator were evaluated by applying an alternative single equation estimator, such as the dynamic OLS (DOLS) procedure. The prime benefit of the DOLS approach was that it considered the presence of a mixed order of integration of the respective variables in the cointegrated framework. The estimation of DOLS involved regressing one of the $I(1)$ variables against other variables, some of which are $I(1)$ with leads (p) and lags ($-p$) of the first difference and others are $I(0)$ variables that include a constant term [75]. Thus, this estimator solved two important limitations: a possible endogeneity problem and small sample bias. Moreover, the obtained cointegrating vectors from DOLS estimators were asymptotically efficient.

The result from DOLS was consistent with the ARDL according to the sign and significance of the coefficient as presented in Table 8. The negative and statistically significant coefficient of LGDPC indicated that CO_2 emissions decreased with a rise of GDP growth during the first phase of the sample years. This finding was compatible with the history of economic growth in Malaysia. From 1970 to 1980, the primary sector mainly agriculture contributed 42.7–33.0% of the total GDP [6]. Based on this fact, the primary sector was shown to be much less responsible for the CO_2 emissions than the manufacturing sector, which is reflected in the results of this study. However, the coefficient of the quadratic form of the LGDPC was positive and statistically significant, which indicated that during 1980–2009, an increase in GDP growth intensified the CO_2 emissions. This finding might be explained

Table 8
Results from the dynamic OLS.

CO ₂ emissions	Coefficient	Robust std. error	z	P-value
LGDPC	-0.0126***	0.0045	-2.8200	0.0050
LGDPCS	0.0029***	0.0003	8.7100	0.0000
LEUC	0.0002***	0.0000	14.8600	0.0000
POPG	0.0066	0.0279	0.2400	0.8140
Constant	0.8479	0.0744	11.38	0.0000
R^2 :	0.967			

Note: Statistically significant at 1% (***) 5% (**) and 10% (*) level.

by Malaysia's economic growth from 1980 onwards, when the manufacturing sectors expanded sharply. The transition of economic growth from primary to secondary sector caused a significant amount of energy demands; consequently, the trend of CO₂ emissions followed a U-shaped direction. Fig. 2 also shows that the CO₂ emissions increased sharply from 1980. The coefficient of energy use was still positive and significant, which was consistent with the long-run coefficient of the ARDL estimators. However, the impact of the population growth was still insignificant on the CO₂ emissions for the Malaysian economy.

6.2. SLM U test – sufficient condition for a quadratic relationship

As previously mentioned, the estimation of the ARDL model takes the quadratic form of the LGDPC that fulfilled the necessary conditions for the existence of a U-shaped or an inverted U-shaped relationship; however, according to SLM U test, these conditions are not sufficient. To fulfil the sufficient conditions, the SLM U test noted that the conventional econometric model is no longer suitable to test the composite null hypothesis that is decreasing at the left side of interval relationship and increasing at the right side of the interval, or vice-versa. Thus, further confirmation of the existence of a U-shape requires to perform Sasabuchi–Lind–Mehlum U test [66]. To accomplish this task, the following model should be estimated:

$$\text{LCO}_{2t} = a\text{GDPG}_t + b\text{GDPG}_t^2 + Z_t C + \varepsilon_t \quad (5)$$

The joint hypothesis test should then be conducted

$$H_0 : (a + b2\text{GDPG}_{min} \leq 0) \cup (a + b2\text{GDPG}_{max} \geq 0)$$

Table 9
Sasabuchi–Lind–Mehlum test for U-shaped relationships.

	CO ₂ emissions
Slope at LGDPC _{min}	–0.497*** (–2.363)
Slope at LGDPC _{max}	1.458*** (2.384)
SLM test for inverse U shape	2.36
P-value	0.0119

Note: Statistically significant at 1% (***) 5% (**) and 10% (*) level.

This should be conducted against the alternative hypothesis

$$H_1 : (a + b_2 \text{GDPG}_{\min} > 0) \cup (a + b_2 \text{GDPG}_{\max} < 0)$$

where LGDPC_{min} and LGDPC_{max} represent the maximum and minimum value of GDP growth. If the null hypothesis is rejected, this confirms the existence of the U shape.

Table 9 clearly demonstrates that the lower bound slope of the LGDPC is negative (–0.497) and the upper bound slope of the LHFIC is positive (1.458). Both bounds are statistically significant, which means that the null hypothesis of no U-shape is rejected against the alternative hypothesis of the U-shaped relationship between CO₂ emissions and the LGDPC. The negative coefficient of the lower bound and positive coefficient of the upper bound endorse the validity of the results obtained using the ARDL and DOLS approaches.

7. Conclusion

This study found several interesting findings. First, there is an existence of a long-run co-integrating relationship among CO₂ emissions and GDP growth, energy consumption and population growth in Malaysia. Second, the theory of an environmental Kuznets curve is not valid; instead, a U-shaped curve (opposite of EKC) exists by the all approaches, such as, ARDL bounds test, dynamic OLS and SLM U-test. To check the stability of the model variables, the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMQ) plots were used where the residuals were within the critical bounds of the 5% significance level. During the period of 1970–1980, per capita CO₂ emissions decreased with increasing per capita GDP (economic growth); however since 1980–2009, per capita CO₂ emissions increased sharply with a further increase of per capita GDP. Finally, the analysis reveals that both per capita energy consumption and per capita GDP has a long term positive impacts with per capita carbon emissions, but population growth rate has no significant impacts on per capita CO₂ emissions. However, the study suggests that in the long run, economic growth may have an adverse effect on the CO₂ emissions in Malaysia.

Overall, Malaysia is facing an increasing trend of per capita CO₂ emission, GDP and energy consumption while the population growth rate shows decreasing. Thus, the rise of per capita CO₂ emission brings a huge concern to the increasing demand of energy consumption and rapid acceleration of economic growth. Fossil energy still possesses absolute share of the total energy consumption although Malaysia has adopted the Five-fuel Diversification Strategy energy mix since 1999, whereby the five main energy sources are oil, natural gas, coal, hydro and renewable energy. Furthermore, the Government of Malaysia in 2011 passed the Renewable Energy (RE) Act, and launched a roadmap to increase the contribution of RE to the electricity generation mix from less than 1% at present to 5.5% by 2015 [83]. Under the Act,

since December 2011, a Feed-in Tariff (FiT) mechanism is implemented to be paid by the contributions of additional 1% of total electricity bills into RE fund if any consumer used more than 300 kWh of electricity per month. Instead, this mechanism may work as an incentive for energy savings and a motivation to consumers (individual or industry) to offset the incremental electricity cost by applying renewable energy and energy efficiency measures. Thus, significant transformation of low carbon technologies such as renewable energy and energy efficiency could contribute to reduce the emissions and sustain the long run economic growth.

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References

- [1] Grossman GM, Krueger AB. Economic growth and the environment. *Q J Econ* 1995;110(2):353–37.
- [2] NC2. Malaysia's second national communication (NC2) – a report submitted to the United Nations Framework Convention on Climate Change (UNFCCC), Conservation and Environmental Management Division (CEMD), Ministry of Natural Resources and Environment (NRE). Available from: <http://nc2.nre.gov.my/>; 2011 [accessed 25.11.13].
- [3] NEAC. New economic model for Malaysia, Part 1: strategic policy directions, a publication of the National Economic Advisory Council (NEAC), Malaysia. Available from: www.neac.gov.my/; 2009.
- [4] Jorgenson DW, Wilcoxen PJ. Environmental regulation and US economic growth. *RAND J Econ* 1990;21(2):314–40.
- [5] Abdullah AZ, Salamatina B, Mootabadi H, Bhatia S. Current status and policies on biodiesel industry in Malaysia as the world's leading producer of palm oil. *Energy Policy* 2009;37(12):5440–8.
- [6] Hasan Z. Fifty years of Malaysian economic development: policies and achievements. Germany: University Library of Munich; 2007.
- [7] Pao HT, Tsai CM. Multivariate Granger causality between CO₂ emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): Evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. *Energy* 2011;36(1):685–93.
- [8] Arouri M-E, Youssef A, M'henni H, Rault C. Energy consumption, economic growth and CO₂ emissions in Middle East and North African countries. *Energy Policy* 2012;45:342–9.
- [9] Saboori B, Sapri M, Baba MB. Economic growth, energy consumption and CO₂ emissions in OECD (Organization for Economic Co-operation and Development)'s transport sector: a fully modified bi-directional relationship approach. *Energy* 2014;66:150–61.
- [10] Hossain S. Panel estimation for CO₂ emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. *Energy Policy* 2011;39(11):6991–9.
- [11] Friedl B, Getzner M. Determinants of CO₂ emissions in a small open economy. *Ecol Econ* 2003;45:133–48.
- [12] Alam MJ, Begum IA, Buysse J, Huylenbroeck GV. Energy consumption, carbon emissions and economic growth nexus in Bangladesh: cointegration and dynamic causality analysis. *Energy Policy* 2012;45:217–25.
- [13] Dean JM, Lovely ME, Wang H. Are foreign investors attracted to weak environmental regulations? Evaluating the evidence from China. *J Dev Econ* 2009;90(1):1–13.
- [14] Weber CL, Peters GP, Guan D, Hubacek K. The contribution of Chinese exports to climate change. *Energy Policy* 2008;36(9):3572–7.
- [15] Yunfeng Y, Laike Y. China's foreign trade and climate change: a case study of CO₂ emissions. *Energy Policy* 2010;38(1):350–6.
- [16] Bloch H, Rafiq S, Salim R. Coal consumption, CO₂ emission and economic growth in China: empirical evidence and policy responses. *Energy Econ* 2012;34(2):518–28.
- [17] Choi Y, Zhang N, Zhou P. Efficiency and abatement costs of energy-related CO₂ emissions in China: a slacks-based efficiency measure. *Appl Energy* 2012;98:198–208.
- [18] Hang G, Yuan-sheng J. The relationship between CO₂ emissions, economic scale, technology, income and population in China. *Proc Environ Sci* 2011;11:1183–8.
- [19] Wang SS, Zhou DQ, Zhou P, Wang QW. CO₂ emissions, energy consumption and economic growth in China: a panel data analysis. *Energy Policy* 2011;39(9):4870–5.

[20] Ozturk I, Acaravci A. CO₂ emissions, energy consumption and economic growth in Turkey. *Renew Sustain Energy Rev* 2010;14(9):3220–5.

[21] Baek J, Kim HS. Is economic growth good or bad for the environment? Empirical evidence from Korea. *Econ* 2013;36:744–9.

[22] Kim J, Li S, Kim KR, Stohl A, Mühlé J, Kim SK, et al. Regional atmospheric emissions determined from measurements at Jeju Island, Korea: halogenated compounds from China. *Geophys Res Lett* 2010;37:12.

[23] Tiwari AK. Energy consumption, CO₂ emissions and economic growth: evidence from India. *J Int Bus Econ* 2011;12(1):85–122.

[24] Essien AV. The relationship between economic growth and CO₂ emissions and the effects of energy consumption on CO₂ emission patterns in Nigerian economy (April 13, 2011). Available at SSRN: <http://ssrn.com/abstract=2148916> or <http://dx.doi.org/10.2139/ssrn.2148916>; 2011.

[25] Menyah K, Wolde-Rufael Y. CO₂ emissions, nuclear energy, renewable energy and economic growth in the US. *Energy Policy* 2010;38(6):2911–5.

[26] Soytas U, Sari U, Ewing BT. Energy consumption, income and carbon emissions in the United States. *Ecol Econ* 2007;62:482–9.

[27] Warner M. The carbon Kuznets curve: a cloudy picture emitted by bad econometrics? *Resour Energy Econ* 2008;30:388–408.

[28] Selden TM, Song D. Environmental quality and development: is there a Kuznets Curve for air pollution emissions? *J Environ Econ Manag* 1994;27:147–62.

[29] Galeotti M, Manera M, Lanza A. On the robustness of robustness checks of the Environmental Kuznets Curve, working paper 22. Milano: FondazioneEni Enrico Mattei; 2006.

[30] Roberts JT, Grimes PE. Carbon intensity and economic development 1962–91: a brief exploration of the environmental Kuznets curve. *World Dev* 1997;25:191–8.

[31] Cole MA, Rayner AJ, Bates JM. The environmental Kuznets curve: an empirical analysis. *Environ Dev Econ* 1997;2:401–16.

[32] Schmalensee R, Stoker TM, Judson RA. World carbon dioxide emissions: 1950–2050. *Rev Econ Stat* 1998;80:15–27.

[33] Pao HT, Tsai CM. CO₂ emissions, energy consumption and economic growth in BRIC countries. *Energy Policy* 2010;38(12):7850–60.

[34] Lean HH, Smyth R. CO₂ emissions, electricity consumption and output in ASEAN. *Appl Energy* 2010;87:1858–64.

[35] Clausen R, York R. Economic growth and marine biodiversity: influence of human social structure on decline of marine trophic levels. *Conserv Biol* 2008;22(2):458–66.

[36] Roca J, Padilla E, Farre M, Galletto V. Economic growth and atmospheric pollution in Spain: discussing the environmental Kuznets curve hypothesis. *Ecol Econ* 2001;39:85–99.

[37] Dietz S, Adger WN. Economic growth, biodiversity loss and conservation effort. *J Environ Manag* 2003;68(1):23–35.

[38] Ekins P. The Kuznets curve for the environment and economic growth: examining the evidence. *Environ Plan* 1997;29(5):805–30.

[39] Mills JH, Waite TA. Economic prosperity, biodiversity conservation, and the environmental Kuznets curve. *Ecol Econ* 2009;68(7):2087–95.

[40] Caviglia-Harris JL, Chambers D, Kahn JR. Taking the U out of Kuznets: a comprehensive analysis of the EKC and environmental degradation. *Ecol Econ* 2009;68(4):1149–59.

[41] Holtz-Eakin D, Selden TM. Stoking and fires? CO₂ emissions and economic growth. *J Public Econ* 1995;57:85–101.

[42] De Bruyn S, Van den Berg J, Opschoor J. Economic growth and emissions: reconsidering the empirical basis of environmental Kuznets curves. *Ecol Econ* 1998;25:161–75.

[43] Lantz V, Feng Q. Assessing income, population, and technology impacts on CO₂ emissions in Canada: where's the EKC? *Ecol Econ* 2006;57:229–38.

[44] Shafik N. Economic development and environmental quality: an econometric analysis. *Oxf Econ Pap* 1994;46(5):757–73.

[45] Omri A. CO₂ emissions, energy consumption and economic growth nexus in MENA countries: evidence from simultaneous equations models. *Energy Econ* 2013;40:657–64.

[46] Ozturk I, Acaravci A. CO₂ emissions, energy consumption and economic growth in Turkey. *Renew Sustain Energy Rev* 2010;14(9):3220–5.

[47] Masih AMM, Masih R. Energy consumption, real income and temporal causality: results from a multi-country study based on cointegration and error-correction modeling techniques. *Econ* 1996;18(3):165–83.

[48] Stern DI. A multivariate cointegration analysis of the role of energy in the US macroeconomy. *Econ* 2000;22(2):267–83.

[49] Shiu A, Lam PL. Electricity consumption and economic growth in China. *Energy Policy* 2004;32(1):47–54.

[50] Masih AMM, Masih R. On temporal causal relationship between energy consumption, real income and prices: some new evidence from Asian energy dependent NICs based on a multivariate cointegration/vector error correction approach. *J Policy Model* 1997;19(4):417–40.

[51] Asafu-Adjaye J. Biodiversity loss and economic growth: a cross-country analysis. *Contemp Econ Policy* 2003;21(2):173–85.

[52] Oh W, Lee K. Causal relationship between energy consumption and GDP revisited: the case of Korea 1970–1999. *Energy Econ* 2004;26(1):51–9.

[53] Yoo S. Electricity consumption and economic growth: evidence from Korea. *Energy Policy* 2005;33(12):1627–32.

[54] Wolde-Rufael Y. Disaggregated industrial energy consumption and GDP: the case of Shanghai, 1952–1999. *Energy Econ* 2004;26(1):69–75.

[55] Soytas U, Sari U. Energy consumption and GDP: causality relationship in G-7 countries and emerging markets. *Energy Econ* 2003;25(1):33–7.

[56] Saboori B, Sulaiman J, Mohd S. Economic growth and CO₂ emissions in Malaysia: a cointegration analysis of the Environmental Kuznets Curve. *Energy Policy* 2012;51:184 (–19).

[57] Leong YP, Mustapha SI, Hashim AH. Climate change challenges on CO₂ emission reduction for developing countries: a case for Malaysia's Agenda for action. *Int J Clim Change: Impact Responses* 2011;2.

[58] Johari A, Ahmed SI, Hashim H, Alkali H, Ramli M. Economic and environmental benefits of landfill gas from municipal solid waste in Malaysia. *Renew Sustain Energy Rev* 2012;16(5):2907–12.

[59] Bari MA, Pereira JJ, Begum RA, Abidin RDZRZ, Jaafar AH. The role of CO₂ emission in energy demand and supply. *Am J Appl Sci* 2012;9(5):641–6.

[60] Jargowsky AP. Omitted variable bias. *Encycl Soc Meas* 2005;2:919–24.

[61] Ang JB. Economic development, pollutant emissions and energy consumption in Malaysia. *J Policy Model* 2008;30:271–8.

[62] Gan PY, Li Z. An econometric study on long-term energy outlook and the implications of renewable energy utilization in Malaysia. *Energy Policy* 2008;36:890–9.

[63] Azlina AA, Mustapha NH. Energy, economic growth and pollutant emissions nexus: the case of Malaysia. *Proc-Soc Behav Sci* 2012;65:1–7.

[64] Nelson CR, Plosser C. Trends and random walks in macroeconomic time series: some evidence and implications. *J Monet Econ* 1982;10(2):139–62.

[65] Gonzalo J. Five alternative methods of estimating long-run equilibrium relationships. *J Econom* 1994;60(1):203–33.

[66] Lind JT, Mehlim H. With or without U? the appropriate test for a U-shaped relationship. *Oxf Bull Econ Stat* 2010;72(1):109–18.

[67] EIA. Annual energy outlook 2006. Energy Information Administration (EIA). Washington; 2006.

[68] Bongaarts J. Population growth and global warming. *Popul Dev Rev* 1992; 299–319.

[69] Pesaran MH, Shin Y, Smith RJ. Bounds testing approaches to the analysis of level relationships. *J Appl Econom* 2001;16(3):289–326.

[70] Pesaran MH, Pesaran B. Working with Microfit 4.0: interactive econometric analysis. United Kingdom: Oxford University Press; 1997.

[71] Elliott G, Rothenberg TJ, Stock JH. Efficient tests for an autoregressive unit root. *Econometrica* 1996;64:813–36.

[72] Narayan P. The saving and investment nexus for China: evidence from cointegration tests. *Appl Econ* 2005;37:1979–90.

[73] World Bank. World development indicators. Geneva; 2010.

[74] Al-Mamun M, Sohag K, Mia MAH, Uddin GS, Ozturk I. Regional differences in the dynamic linkage between CO₂ emissions, sectoral output and economic growth. *Renew Sustain Energy Rev* 2014;38:1–11.

[75] Alcántara V, Padilla E. Input–output subsystems and pollution: application to the service in Spain. *Ecol Econ* 2008;68(3):905–14.

[76] Brock WA, Taylor MS. Economic growth and the environment: a review of theory and empirics. *Handb Econ Growth* 2005;1:1749–821.

[77] Dinda S, Coondoo D. Income and emission: a panel data-based cointegration analysis. *Ecol Econ* 2006;57(2):167–81.

[78] Managi S, Jena PR. Environmental productivity and Kuznets curve in India. *Ecol Econ* 2008;65:432–40.

[79] Jalil A, Mahmud S. Environment Kuznets curve for CO₂ emissions: a cointegration analysis for China. *Energy Policy* 2009;37:5167–72.

[80] Park S, Lee Y. Regional model of EKC for air pollution: evidence from the Republic of Korea. *Energy Policy* 2011;39(10):5840–9.

[81] Lotfaliipour RM, Falahi MA, Ashena M. Economic growth, CO₂ emissions, and fossil fuels consumption in Iran. *Energy* 2010;35(12):5115–20.

[82] Chen Yan, et al. Fundamental trade-offs on green wireless networks. *IEEE Commun Mag* 2011;49(6):30–7.

[83] Energy Commission. National energy balance 2011, ministry of energy, green technology and water. Available from: www.st.gov.my; 2011.